# Comparisons of lidar derived humidification factors to surface optical and chemical measurements during the Combined HSRL and Measurement Study (CHARMS) at the DOE ARM Southern Great Plains site in northern Oklahoma

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## 1. Introduction

The Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility makes remote sensing measurements of atmospheric aerosols and clouds using a variety of instrumentation providing high-quality characterization of the ambient atmosphere. The CHARMS campaign took place in northern Oklahoma at the Southern Great Plains site in the summer of 2015. During CHARMS, the University of Wisconsin High Spectral Resolution Lidar (HSRL) was deployed next to the DOE ARM SGP Raman lidar in order to acquire multiwavelength profiles of aerosol backscatter and extinction. HSRL acquired profiles of aerosol backscatter at 532 and 1064 nm and aerosol extinction and depolarization at 532 nm. The SGP Raman lidar acquired profiles of aerosol backscatter and extinction at 355 nm as well as profiles of water vapor mixing ratio. Profiles of relative humidity were derived from Raman lidar water vapor profiles and temperature profiles derived from simultaneous measurements from the SGP Atmospheric Emitted Radiance Interferometer (AERI). The ARM facility at SGP also had surface measurements of chemical composition from the Aerosol Chemical Speciation Monitor (ACSM) and humidification factors from surface-located humidity scanning nephelometers. The combination of these instruments provided a basis to explore lidar-derived ambient humidification factor compared to measurements from ground-based nephelometers and derived from ground-based measurements of aerosol chemical composition.

## 2. Methods

Certain layers of the lidar profiles were selected based on the criteria in Table 1a. These criteria were used to isolate regions and periods where changes in aerosol properties were due to changes in RH and not aerosol concentration/type.

*Table 1a. Analysis region selection criteria*

| |
|---|
| Daytime |
| At or below aerosol Mixed Layer Height |
| $\partial r/\partial z \approx 0$; water vapor mixing ratio gradient |
| $\partial \theta_v/\partial z \approx 0$; potential temperature gradient |
| $\partial \alpha/\partial RH > 0$; extinction monotonic + with RH |

*Table 1b. Statistical summary*

| |
|---|
| Num. Profiles (N>10): 1498 |
| MLH = 1.15 ± 0.7 km |
| $\partial r/\partial z$ = -1 ± 2.3 g/kg·km |
| $\partial \theta_v/\partial z$ = 2.7 ± 1.7 K/km |
| 19.6% < RH < 93.1% |

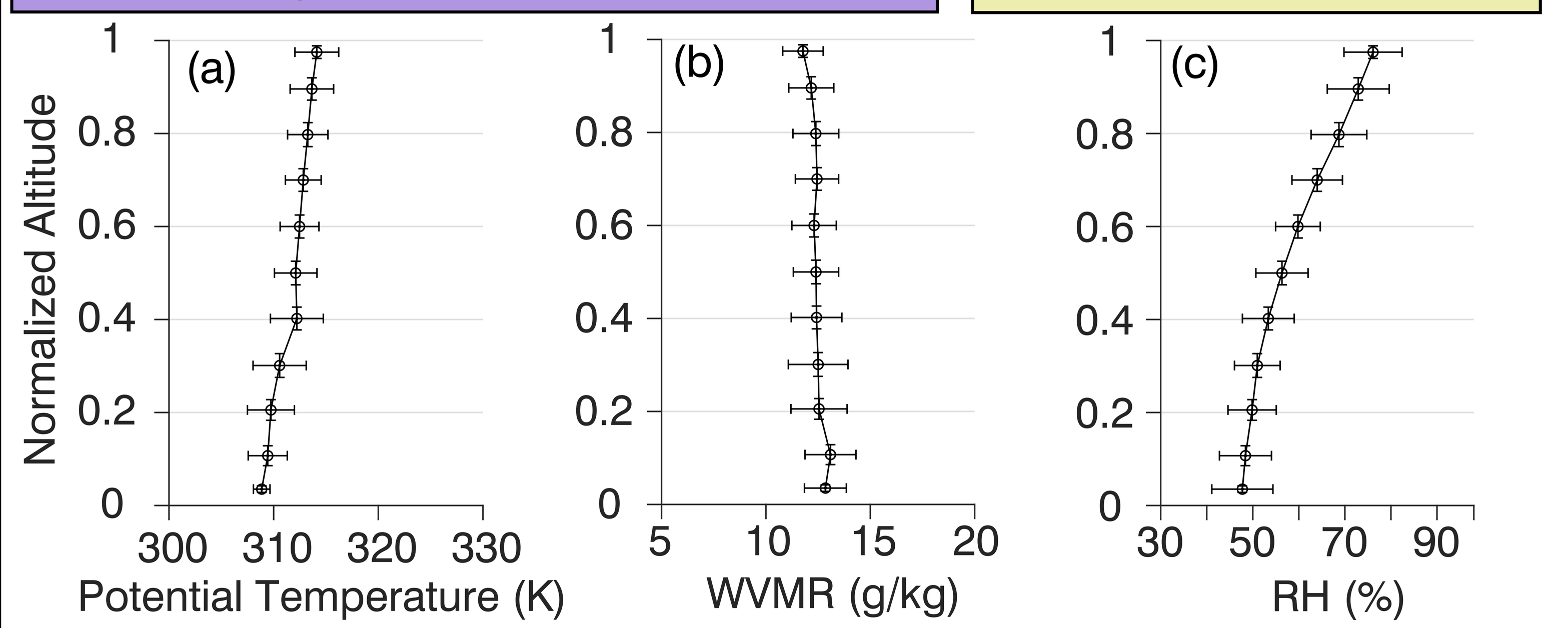



**Figure 1.** Meteorological summary of lidar profiles analyzed during the summer, 2015 CHARMS campaign. Profiles are shown at bin medians for altitudes normalized by the mixed layer height (MLH) determined for each profile and binned in steps of 0.1. The MLH is at $z = z_i = 1$. Bold lines are medians of (a) virtual potential temperature; (b) water vapor mixing ratio; and (c) relative humidity. Thin black lines show the interquartile range.

### Humidification Models

Gamma

$$\alpha = \alpha_0 \left( \frac{100 - RH}{100 - RH_0} \right)^{-\gamma}$$

Kappa-Scattering

$$\alpha = \alpha_0 \left( 1 + \kappa_{sca} \frac{RH}{100 - RH} \right)$$

Each humidification model is simultaneously fit to the lidar retrievals of extinction. The models are fit as a system of equations so that they share a common estimate of the dry extinction coefficient. Profiles are fit as 30 minute moving averages so that the profiles to the left and right influence the fit result.

## 3. Results

### CHARMS Campaign Summary Plots (N =1739 profiles)

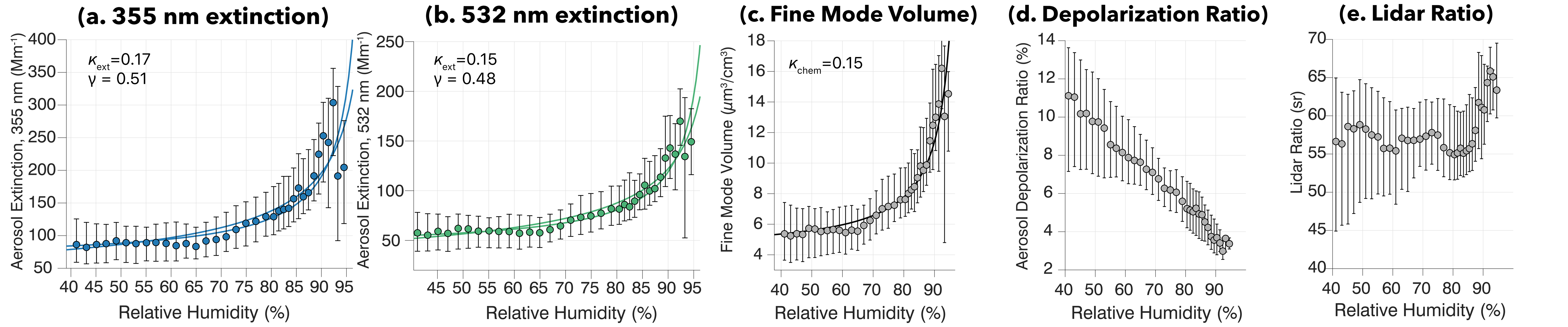



**Figure 2.** (a) Raman Lidar 355 aerosol extinction as a function of Raman lidar derived Relative Humidity; (b) HSRL Lidar 532 aerosol extinction; (c) 3β + 2α optimal estimation derived fine mode volume; (d) HSRL measured aerosol depolarization ratio and (e) HSRL measured lidar ratio (i.e. extinction over backscatter). Bullets are medians and bars are the interquartile range.

### Case Study: August 2-3, 2015

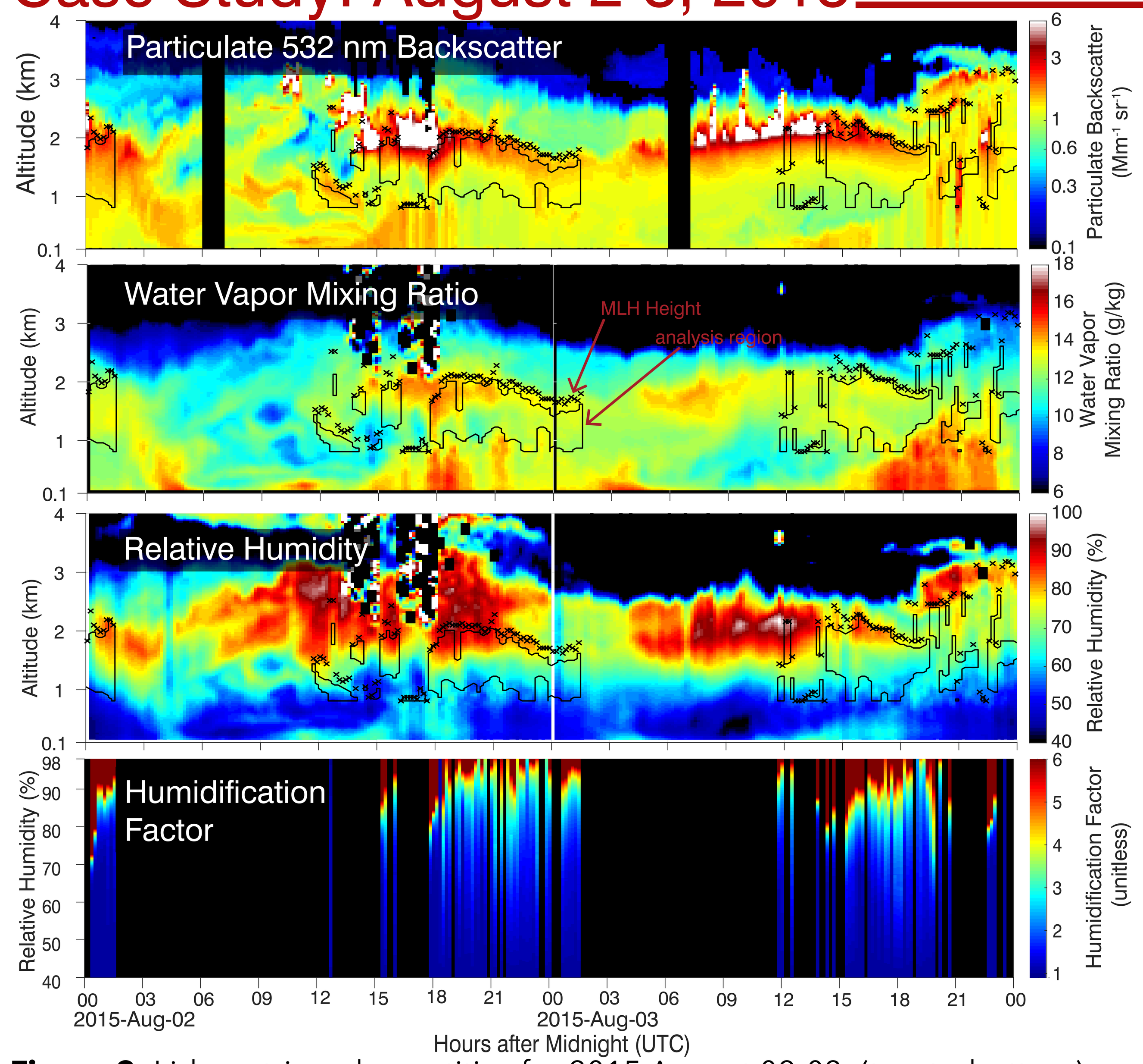



**Figure 3.** Lidar retrieved quantities for 2015 August 02-03; (top-to-bottom) HSRL measured aerosol backscatter. Mixed Layer Height (MLH) delineated by black crosses and regions analyzed for finding humidification factor delineated by black contour; Raman measured water vapor mixing ratio; Raman derived relative humidity; Lidar-derived humidification factor

### Steps for Model Comparisons to f(RH)

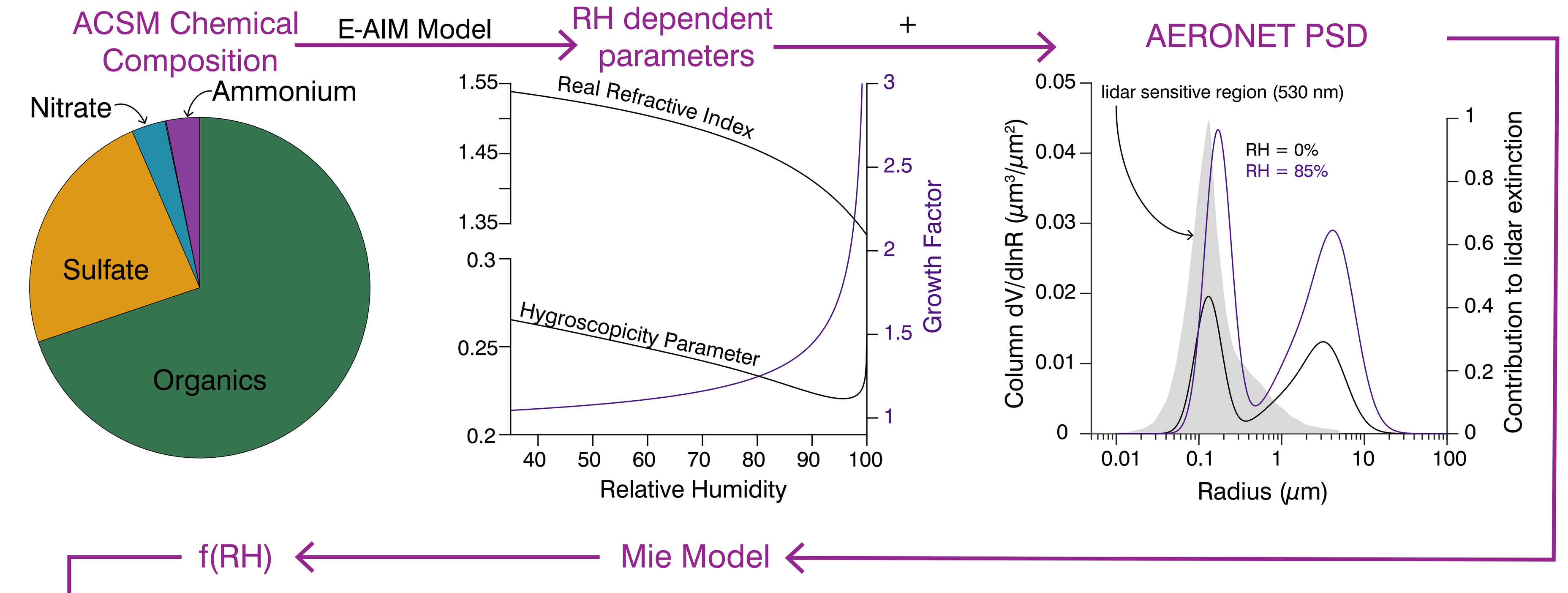
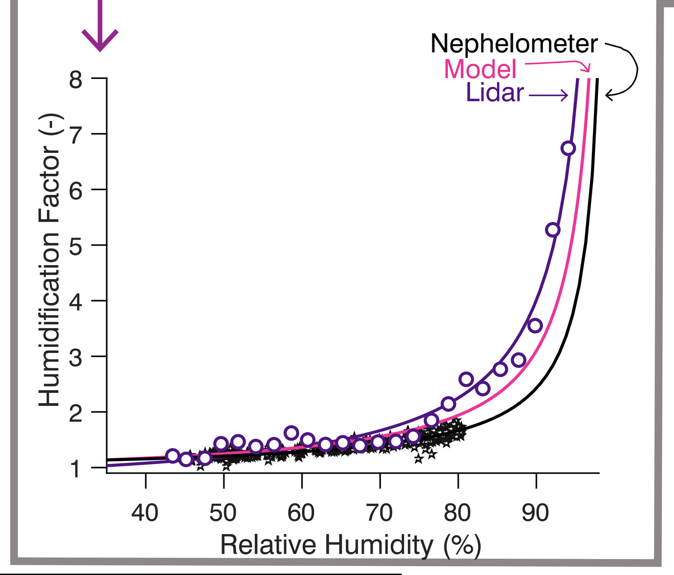



**Figure 4.** Required model inputs for calculating f(RH) are shown from left to right




### Impacts of Cloudy Regions on Retrievals

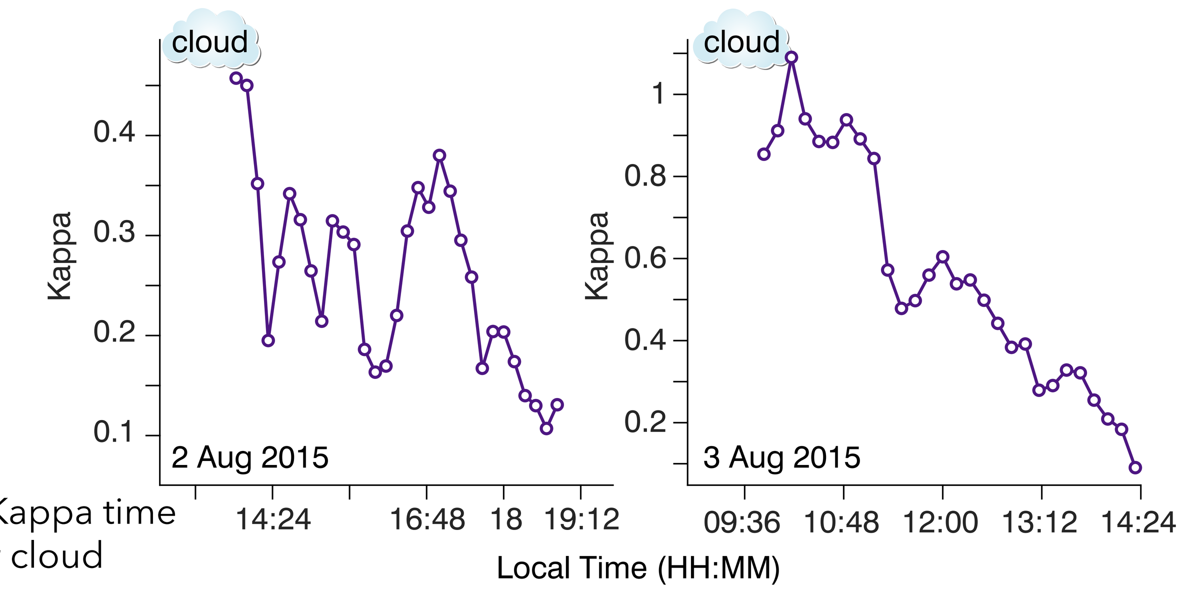



**Figure 5.** Kappa time series after cloud

## 4. Summary and Conclusions

- Aerosol extinction and relative humidity profiles were derived from lidar measurements acquired at the DOE ARM SGP site in northern Oklahoma.
- Lidar measurements of the aerosol humidification factor were shown to lie within expected values based on surface measurements of humidification factors and estimated humidification factors assuming surface chemical composition and AERONET retrieved size distributions.
- Changes in the aerosol size distribution contributed to increased hygroscopicity in the estimated humidification factor and probably in lidar retrievals compared to surface nephelometer measurements.
- A time delay of the lidar-retrieved extinction hygroscopicity parameter (kappa) relating to cloud effects was observed. Lidar contributions to understanding aerosol-cloud interactions will be a future focus.

## 5. Acknowledgements

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## 6. References

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